

SCORING TESTS OF AIRCRAFT TRANSMISSION LUBRICANTS AT HIGH SPEEDS AND HIGH TEMPERATURES

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Aircraft engines always contain gears that have to be lubricated under conditions of high speeds and extremely high temperatures. In this field of application scoring damage can be likely to occur. In Europe and partly also in the USA the scoring load capacity of gear oils is expressed in terms of FZG Scoring Load Stage. The FZG Gear Test Rig is described. The normal test procedure A/8.3/90 as standardized in DIN 51 354 using A-type gears at a pitch line velocity of $v = 8.3$ m/s and a starting oil temperature of 90°C is presented. A modified procedure at double speed and increased oil temperature A/16.6/140 is discussed. The scoring load capacity of aircraft transmission lubricants is worldwide expressed in Ryder Gear Test results. Because of the high costs and problems with the availability of test gears a modified FZG Ryder Test was developed. The method is presented and comparative results of typical aircraft engine oils in the FZG, the FZG-Ryder and the original Ryder Gear Test are shown. From this experience it becomes obvious that alternative test methods for the evaluation of scoring load capacity of aircraft transmission lubricants can be available in the near future.

1. Introduction

With increasing power transmission per volume, increasing speeds and increasing temperatures the demands on lubricants for application in aircraft gearing have increased accordingly. Besides physical properties like viscosity and chemical properties like oxidation stability the technological properties like scoring load capacity have to be tested under conditions close to practice. As scoring is affected by different properties of the lubricant - viscosity as well as chemical composition - gear test procedures were developed and compared with the behavior of the lubricant in practice. These test methods are the Ryder Gear Test in the USA, the IAE test in Great Britain, and the FZG test in Germany. In the following, test procedures on the FZG back-to-back gear test rig and results with aircraft lubricants are described.

2. Standard Test A/8.3/90

The test rig is of the back-to-back type with a mechanical power circuit. The test torque is applied by lever and weights at the load clutch and can easily be calibrated and controlled through the distortion of the torsional shaft (see Fig. 1). A specially designed gear profile, so-called A-type gears with high sliding and thus with high scoring risk are used. Fig. 2 shows the gear profile with the velocity and pressure distribution along the path of contact; table 1 gives the main gear data. Under conditions of dip lubrication at starting oil temperature of 90°C the gears are run for 15 min. in one load stage (Fig. 3). The load is increased stepwise in 12 load stages until scoring occurs on the flanks. The oil bath is not cooled so that a maximum oil temperature in the twelfth load stage of approx. 140°C is reached. Scoring failure can be assessed either by visual control (Fig. 4) or by weighing the gears after each load stage and plotting the weight loss against transmitted work (Fig. 5). A steep increase in weight loss indicates scoring failure. The scoring load stage is reported and for the gravimetric method the specific wear rate gives an additional value on the relative wear behaviour of the lubricant.

This test method is standardized in Germany in DIN 51 354 /1/ and in Europe in CEC L-07-A-71 /2/. The results of the test express a relative rating of scoring load capacity of different oils. Calculation procedures were established in DIN 3990 and ISO 6336 /3, 4, 5/ for the calculation of the scoring risk of practical gears using the FZG scoring load stage as the "strength value" for the lubricant. Results for typical aircraft oils in the FZG standard test A/8.3/90 are shown in Fig. 6. The relative rating is comparable with results of the Ryder Gear test with these oils.

3. Special Test A/16.6/140

As high performance EP gear oils usually passed the 12 load stages without failure a modified, more severe test procedure at an increased speed of $v = 16.6$ m/s and for high temperature application at starting oil temperature of 140°C was established /6/. Because the oil is not cooled during the test temperatures up to $180 - 200^\circ\text{C}$ are reached in load stage 12 of this procedure. Again the results of aircraft lubricants are shown in Fig. 7. It is interesting to note the very high scoring load obtained with the Shell 0-160 oil compared with the standard test. The result was proved by duplicate testing.

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According to Maier /7/ a very rapid decrease of the oil performance as related to scoring is observed. This is confirmed with tests on used oils vs new oil in the A/16.6/140 procedure as shown in Fig. 8. Significant reductions in scuffing performance can be seen with increasing use of the oil /7/.

4. FZG Ryder Test R/46.5/74

From different research projects /8, 9, 10, 11/ it is known, that the scoring behavior of different lubricant types with increasing velocity may be very different. In Fig. 9 the scoring load for different base oils and different additive systems is plotted against velocity. From this graph it is evident that a different ranking of the oils is possible when tests are performed at different pitch line velocities.

Because of the high costs of the Ryder test rig and test gears as well as problems with the availability of test gears, a research project was initiated and funded by the German Ministry of Defence. The aim was to develop a test rig and test procedure on a modified FZG test rig which gave equivalent results as compared to Ryder Gear Tests /12/ (Fig. 10).

The principle of the test rig can be taken from Fig. 11. Table 2 lists the differences in the rig design as compared with the original Ryder rig. Because of almost the same center distance of the two rigs FZG R-type gears (Fig. 12) could be designed very close to the original Ryder gears. A comparison of the main gear data is given in Table 3. Table 4 shows a comparison of the gear materials used.

Fig. 13 shows the test procedure. The oil to be tested is heated to the test temperature of 74°C. For every test an oil quantity of approx. 5 l is necessary. The oil is sprayed on the gears at a flow rate of approx. 0.5 l/min. Then the torque of load stage 1 is applied. The load in every load stage can be taken from table 5. The motor is started; the running time is 10 min per load stage. After every load stage the gears are inspected with a microscope and the scored area on each flank is recorded. For this purpose a grid is incorporated in the microscope such that each square represents 5% of the active flank area of a tooth. Thus the location and the size of the scoring marks can easily be recorded. The percentage of damage in each load stage is determined and plotted against the load in a logarithmic chart (Fig. 14). The test is terminated when more than 30% of the active flank is scored. Scoring load is interpolated as the normal tooth load when 22.5% of the flank shows scoring failure. The test on one oil is run with both flanks of the test gear. As result the mean value of all test runs as well as every single result is recorded.

In the course of the investigations a variety of different lubricants - straight mineral oils, mineral based EP oils and different synthetic lubricants - were tested in the FZG Ryder Test and compared to results obtained in the original Ryder machine. The results are plotted in Fig. 15. Fig. 16 shows comparative results for typical aircraft oils in the original Ryder /12/ and the FZG-Ryder test. A very good correlation is observed. In the next few months comparative testing of some commercial oils from different manufacturers and different specification will be done.

The first investigations were started with increased oil temperature to address the increased temperatures in turbines of the future. Tests with 0-160 were performed at 115°C instead of 74°C. The results are shown in Fig. 16. By a modification of the oil spray device even higher temperatures can be achieved when high temperature testing is necessary.

5. Conclusion

Different test methods on modified FZG back-to-back gear test rigs under high speed and high temperature conditions were discussed.

For the evaluation of typical aircraft lubricants a new test procedure FZG R/46.5/74 showed good correlation with test results in Ryder Gear Testing. The costs of the modified FZG test rig and test gears are approximately 25% of a Ryder Gear Test Rig and of original Ryder test gears.

Comparative testing of a wider range of commercial oils will be done in the next couple of months. To meet future requirements of aircraft lubricants in the high temperature range investigations at increased test temperature were started.

6. Acknowledgement

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7. References

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- 2 CEC L-07-A-71: Load Carrying Capacity Test For Transmission Lubricants.

- 3 DIN 3990: Grundlagen für die Tragfähigkeitsberechnung von Gerad- und Schrägstirnrädern.
- 4 ISO 6336: Calculation of Load Capacity of Spur and Helical Gears.
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Table 1: Geometry of Test Gears Tooth Profile A

* pitch line velocity in m/s

| | | | |
|-----------------------|---------------|---------|-----|
| Center distance | a | 91.5 | mm |
| pinion | z_1 | 16 | - |
| Number of teeth | z_2 | 24 | - |
| gear | m | 4.5 | mm |
| Module | b | 20 | mm |
| Tooth width | d_{w1} | 73.2 | mm |
| pinion | d_{w2} | 109.8 | mm |
| Pitch diameter | x_1 | 0.8635 | - |
| gear | x_2 | -0.5 | - |
| Addendum modification | α | 20 | deg |
| Pressure angle | α_{wt} | 22.5 | deg |
| recess path | e_1 | 14.7 | mm |
| Length of | e_2 | 3.3 | mm |
| approach path | v_{g1} | 0.67v * | m/s |
| Max. sliding velocity | | | |

| | Original Ryder | FZG-Ryder | Units |
|---------------------|--------------------------------------|--------------------------------|-------|
| load application | axial displacement | torque | |
| load measurement | recalculated from hydraulic pressure | distortion of calibrated shaft | |
| center distance | 88.9 | 91.5 | mm |
| pinion speed | 10 000 | 9706 | rpm |
| pitch line velocity | 46.5 | 46.5 | m/s |
| spray lubrication: | | | |
| oil flow rate | 0.27 | 0.5 | l/min |
| oil temperature | 74 | 74 | °C |

Table 2: Comparison of Machines and Operating Conditions of Original Ryder and FZG Ryder Test

| | | Original Ryder | FZG-Ryder | Units |
|------------------------|---------------|----------------|-----------|---------------|
| center distance | a | 88.9 | 91.5 | mm |
| number of teeth | z_1/z_2 | 28/28 | 30/30 | - |
| module | m | 3.175 | 3.0 | mm |
| working pressure angle | α_{wt} | 22.5 | 22.5 | ° |
| tooth width | b_1/b_2 | 6.35/26 | 6.25/26 | mm/mm |
| tip relief gear | C_{a2} | 0 | 15 | μm |
| relative sliding speed | v_{gmax}/v | 0.28 | 0.28 | - |
| material: | | | | |
| case carburized | | AMS 6260 | 14NiCr14 | - |
| surface hardness | HRC | 60-62 | 60-62 | - |
| surface roughness | CLA | 0.3-0.5 | 0.3-0.5 | μm |

Table 3: Comparison of Original Ryder and FZG Ryder Gears

| mean content of | AMS 6260 | 14 NiCr 14 |
|------------------|----------|------------|
| C | 0.11 % | 0.15 % |
| Si | 0.27 % | 0.25 % |
| Mn | 0.55 % | 0.40 % |
| P _{max} | 0.025 % | 0.035 % |
| S _{max} | 0.025 % | 0.035 % |
| Cr | 1.2 % | 0.80 % |
| Mo | 0.12 % | - |
| Ni | 3.25 % | 3.5 % |

Table 4: Comparison of Gear Materials of Original Ryder and FZG Ryder Gears

| Load Stage | Torque in Nm | Tooth Load | |
|------------|--------------|------------|----------|
| | | in N/mm | in lb/in |
| 1 | 17.5 | 66 | 375 |
| 2 | 35.0 | 131 | 750 |
| 3 | 52.5 | 197 | 1125 |
| 4 | 70.0 | 263 | 1500 |
| 5 | 87.5 | 329 | 1875 |
| 6 | 105.0 | 394 | 2250 |
| 7 | 122.5 | 460 | 2625 |
| 8 | 140.0 | 526 | 3000 |
| 9 | 157.5 | 591 | 3375 |
| 10 | 175.0 | 657 | 3750 |
| 11 | 192.5 | 723 | 4125 |
| 12 | 210.0 | 788 | 4500 |
| 13 | 227.5 | 854 | 4875 |
| 14 | 245.0 | 920 | 5250 |
| 15 | 262.5 | 985 | 5625 |
| 16 | 280.0 | 1051 | 6000 |

Table 5: Load Stages of the FZG Ryder Test

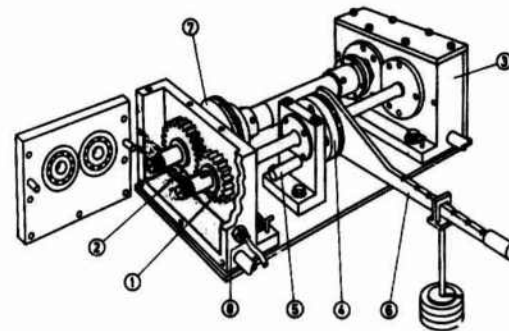


Fig. 1: FZG Gear Test Rig
(Schematic View)

- | | |
|--------------------------------------|---|
| ① PRÜFRITZEL TEST PINION | ⑤ ARRETIERBOLZEN LOCKING PIN |
| ② PRÜFRAD TEST WHEEL | ⑥ BELASTUNGSHEBEL MIT GEWICHTEN LOAD LEVER AND WEIGHTS |
| ③ ÜBERTRAGUNGSGETRIEBE DRIVE GEAR | ⑦ TORSIONSMESKUPPLUNG TORQUE MEASURING CLUTCH |
| ④ BELASTUNGSKUPPLUNG LOAD CLUTCH | ⑧ TEMPERATURFÜHLER TEMPERATURE SENSOR |

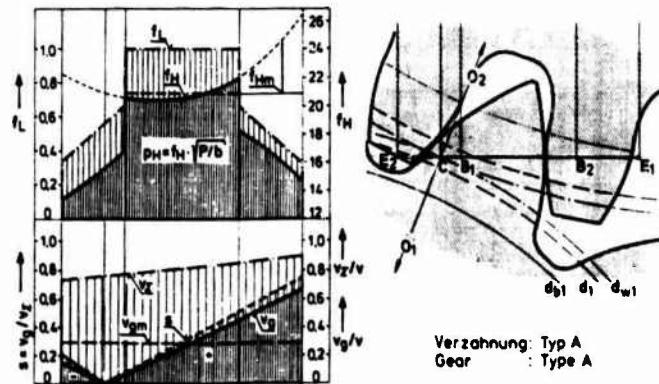


Fig. 2: Load and Speed
Distribution (A Type Gears)

GEAR TYPE A

DIP LUBRICATION WITH STARTING OIL TEMPERATURE AT BEGINNING OF EVERY LOAD STAGE $\theta_{oil} = 90^\circ\text{C}$, WITHOUT COOLING

PITCH LINE VELOCITY $v = 8.3 \text{ m/s}$

DRIVING PINION

LOAD STEPWISE INCREASED UNTIL SCORING OCCURS

FAILURE CRITERION:

VISUAL METHOD: MORE THAN ONE TOOTH WIDTH SCORED AREA

GRAVIMETRIC METHOD: MORE THAN 10 MG OVER THE AVERAGE WEAR RATE

Fig. 3: FZG Scoring Test

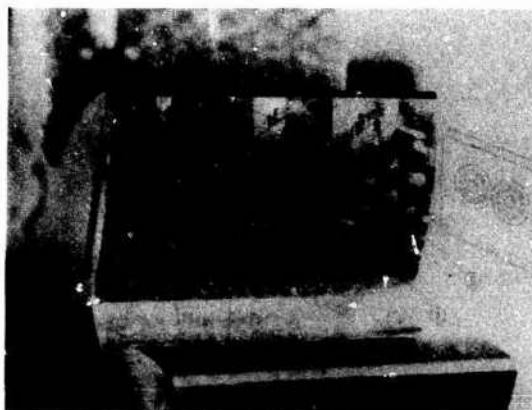


Fig. 4: Flank Appearance Scoring

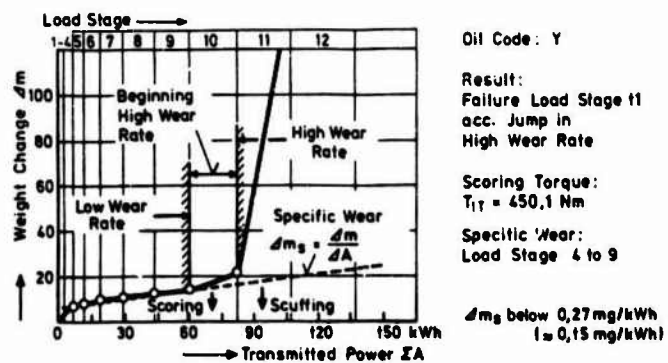


Fig. 5: Result of an FZG Test (Gravimetric Method)

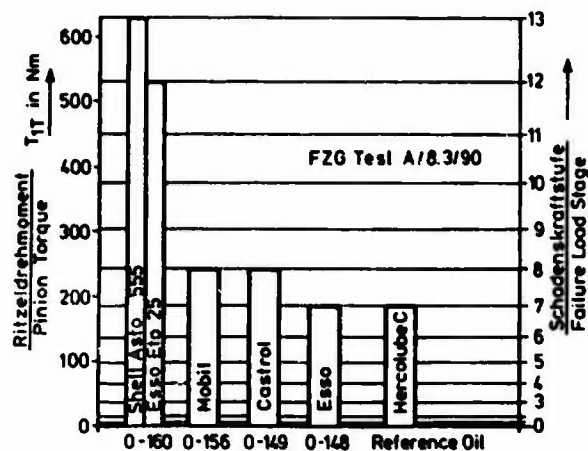


Fig. 6: Scoring Load Capacity of Aircraft Lubricants in the FZG Standard Test A/8.3/90

Fig. 7: Scoring Load Capacity of Aircraft Lubricants in the FZG Special Test A/16.6/140

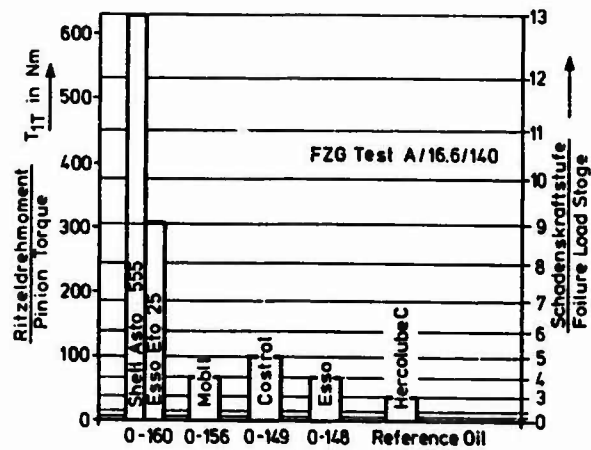


Fig. 8: Decrease of Scoring Load Capacity of Used Oil

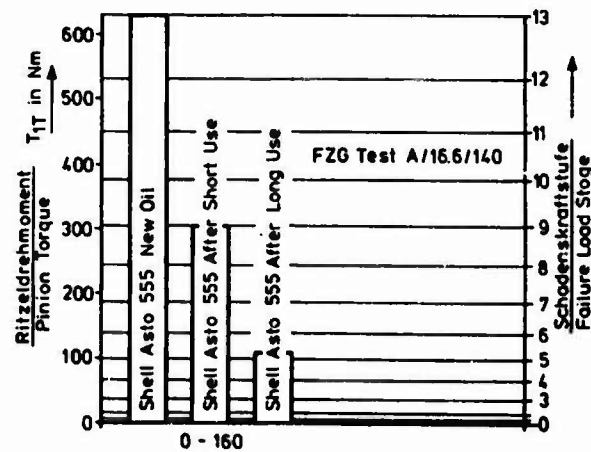
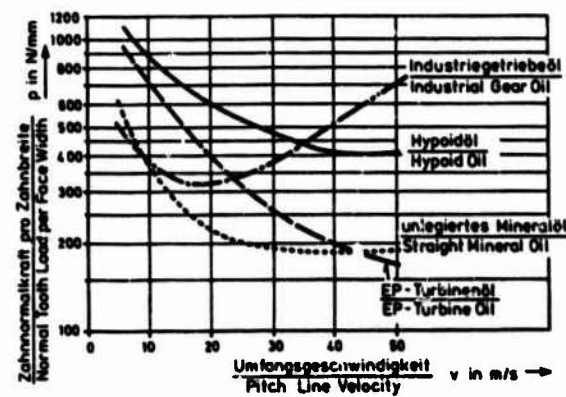


Fig. 9: Scoring Load for Different Gear Oils



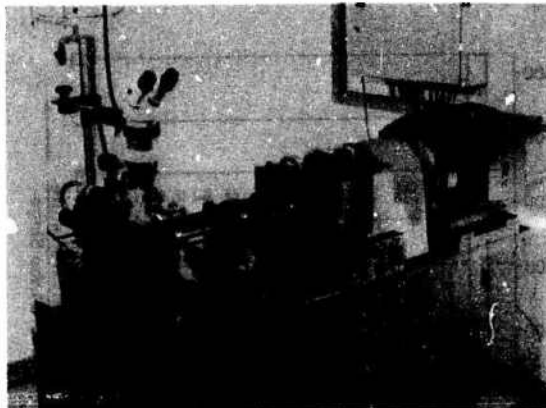


Fig. 10: Photo of the
FZG Ryder Gear Test Rig

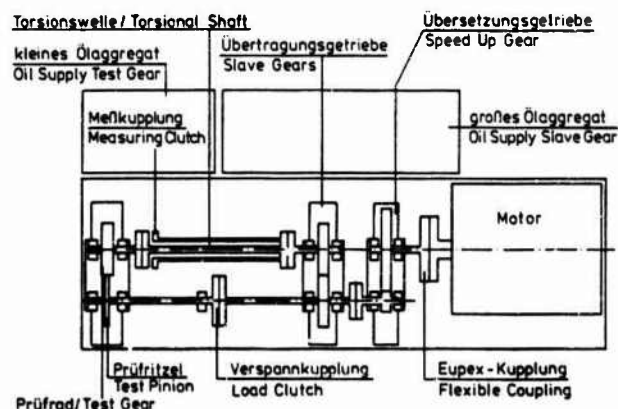


Fig. 11: FZG Ryder Gear Test
Rig (Schematic View)

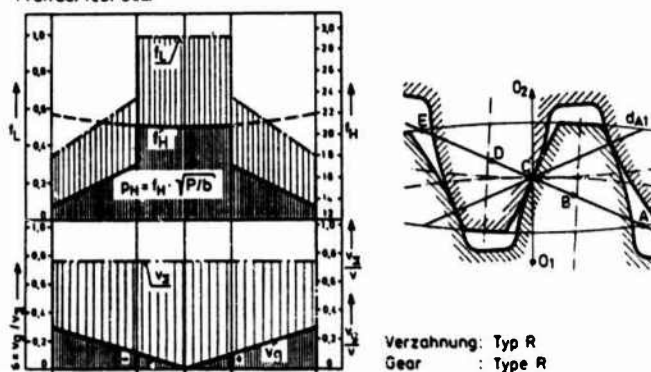


Fig. 12: Load and Speed
Distribution (Gear Type R)

GEAR TYPE R

SPRAY LUBRICATION WITH CONSTANT OIL TEMPERATURE
OF 74°C. OIL FLOW $\dot{V} = 0.5 \text{ L/MIN.}$

PITCH LINE VELOCITY $v = 46.5 \text{ M/S}$
DURATION PER LOAD STEP $t = 10 \text{ MIN}$

LOAD STEPWISE INCREASED UNTIL SCORED
AREA ON THE PINION FLANK EXCEEDS APPR. 30%
OF ACTIVE FLANK

FAILURE CRITERION:
MORE THAN 22.5% OF ACTIVE FLANK AREA SCORED.
SCORING LOAD DETERMINED BY LINEAR INTERPOLATION

Fig. 13: FZG Ryder Test

Fig. 14: Evaluation of Scoring Load in the FZG Ryder Test

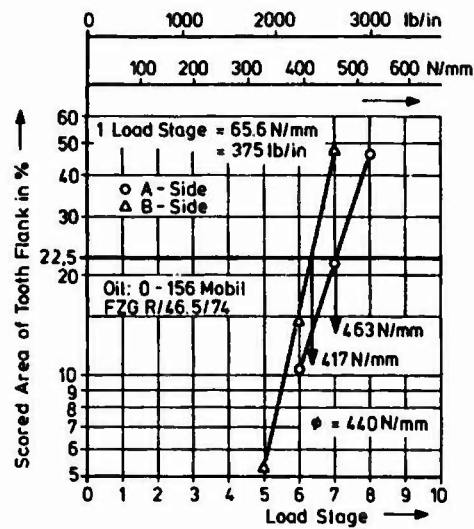


Fig. 15: Comparison of Scoring Load in the Original Ryder and the FZG Ryder Test

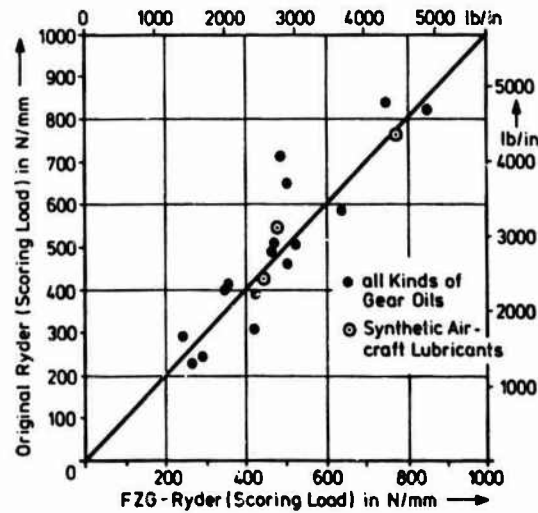


Fig. 16: Comparative Results of Ryder and FZG Ryder Tests for Aircraft Lubricants

